A High Efficiency, Broadband GaN Amplifier for Amateur Radio

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Project Background

- 10-20W, Driver Amplifier for High Power Device Evaluation in the VHF – UHF frequency range
- Educational Project – Introduction to Basic RF Design Techniques
- Evaluation of the potential of a new semiconductor technology – GaN
- Nice HT amplifier for Amateur Satellite Operation

Why GaN Technology?

- GaN HEMTs
  - Gallium Nitride High Electron Mobility Transistor
- Emerging new semiconductor technology with several key advantages over LDMOS and GaAs device technologies.
  - Higher Power Densities
  - High Breakdown Voltage
  - High Operating Temperatures
  - High Input Impedance
  - High Efficiency
  - Higher Frequency Operation – Ku Band
- Manufacturers
  - Eudyna, RFHIC, Toshiba, Cree

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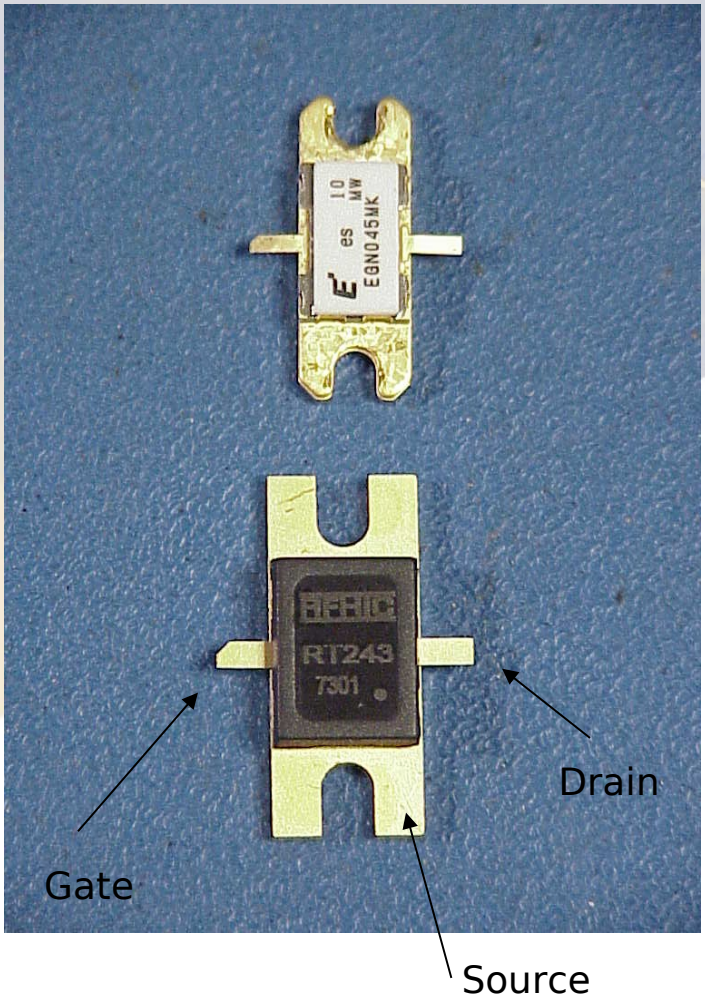
High Efficiency Amplification

- Academic papers are full of discussion of Class E and Class F , high efficiency amplifier operation. Typically will have small operating bandwidths due to required matching and bias points.
- This design is based on traditional Class AB bias familiar with ham radio operators for communication amplifiers.
- Very basic linear design techniques used.
- Goal: To build a 20W amplifier capable of 50-500MHz instantaneous bandwidth. Device used: Eudyna EGN045MK

GaN Devices



- Eudyna EGN045MK

  - High Voltage Operation : V_{DS}=50V
  - High Power : 47.5dBm (typ.) @ P3dB
  - High Efficiency: 60%(typ.) @ P3dB
  - Linear Gain : 12dB(typ.) @ f=2200MHz
  - Broad Frequency Range : 800 to 2200MHz

- RFHIC RT243

  - Frequency Range = 50MHz ~ 4GHz
  - High Output Power

  P_1dB = 43dBm(Typ.)@2.14GHz

  P_3dB = 45dBm(Typ.)@2.14GHz

  - High Efficiency
  - High In/Out Impedance
  - High Power Gain

  G1dB = 16dB(Typ.)@900MHz

  G1dB = 12dB(Typ.)@2.14GHz

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Amplifier Design

- (2) Basic steps to the Amplifier Design
  - DC Bias Circuitry
  - RF Circuit Design

- As an Educational Project it was chosen to use free software available to hams.

  - DC Circuit Design: LTspice/SwitcherCAD III
    - Linear Technology: www.linear.com

  RF Circuit Design: RF Designer SV
    - Ansoft Corp.: www.ansoft.com

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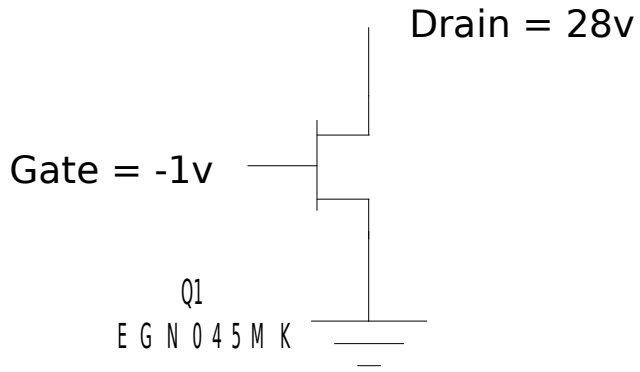
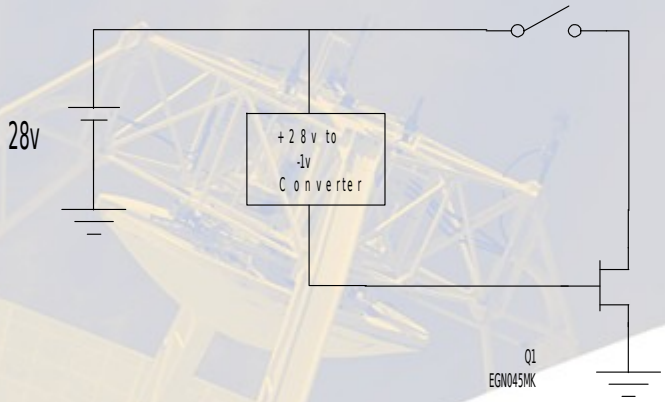
Bias Circuit Design

- GaN HEMT requires negative voltage on the gate (-1v) and positive voltage on drain (28v) with respect to the source (grounded flange).
- For ease of portable operation, we want to operate the amplifier from a single 28v power supply.
  - Need to generate a negative voltage for the gate

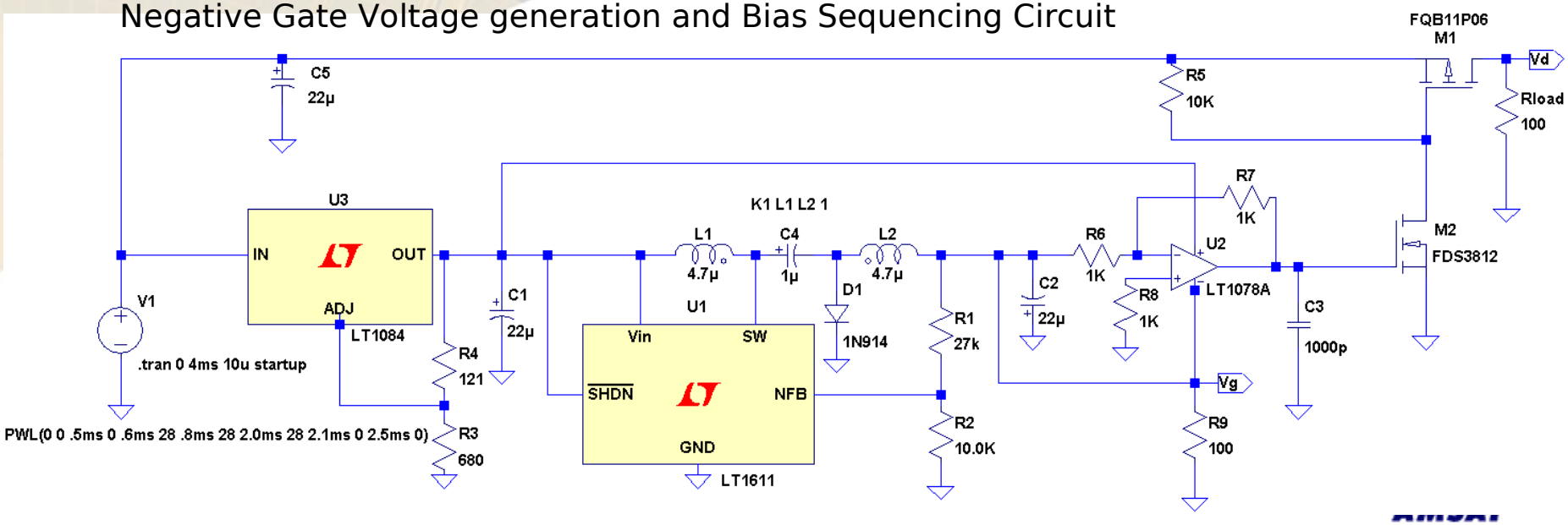


Bias Circuit Design

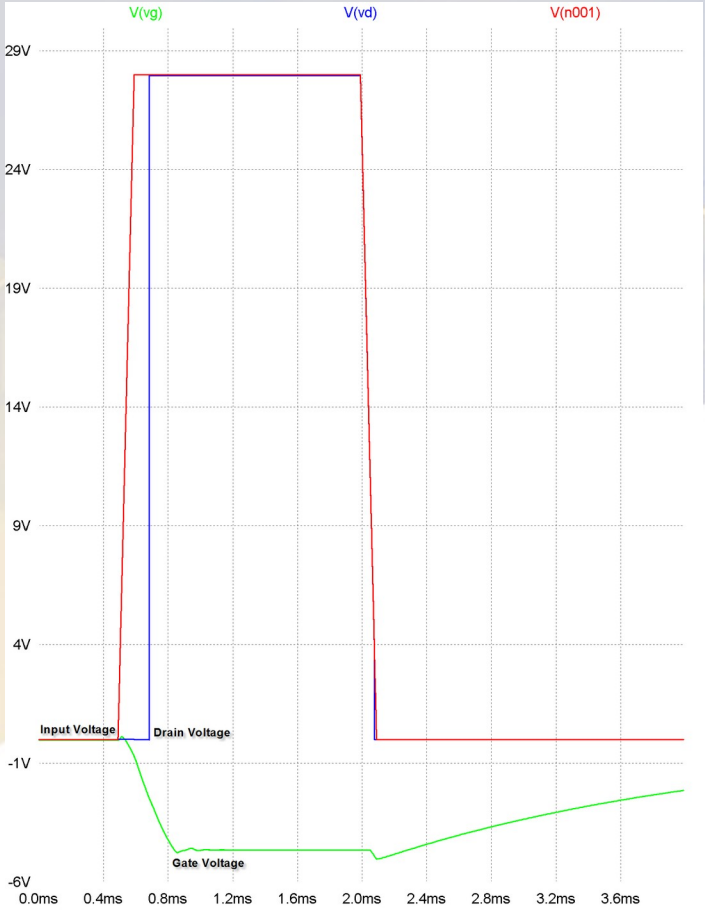


To avoid device damage, the +28v drain bias must be applied after the -1v gate voltage

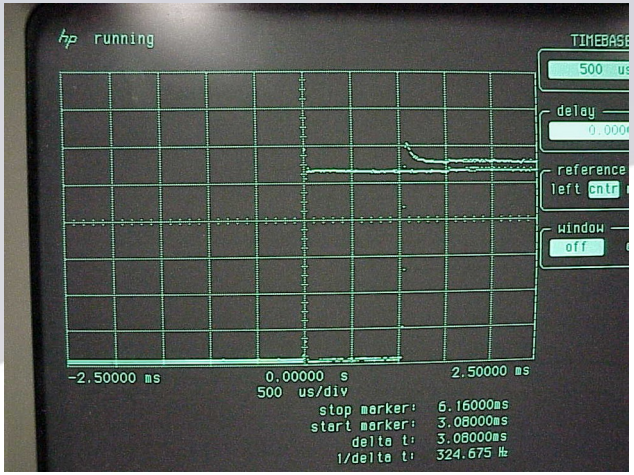
Negative Gate Voltage generation and Bias Sequencing Circuit



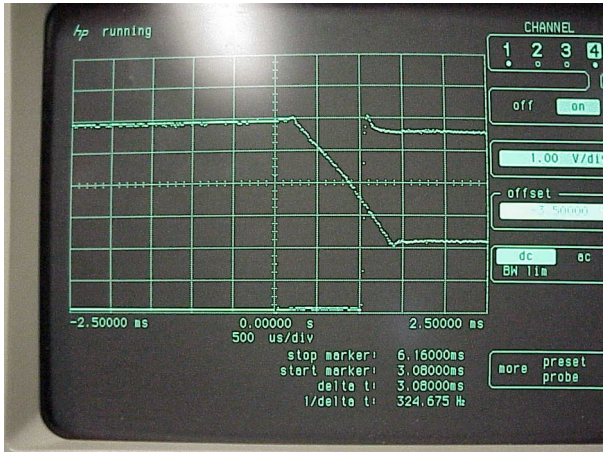
Bias Circuit Design



LTSpice simulation of drain and gate voltage sequencing



Measured 28V Power Supply input and 28v to drain



Measured negative gate voltage vs 28v drain voltage

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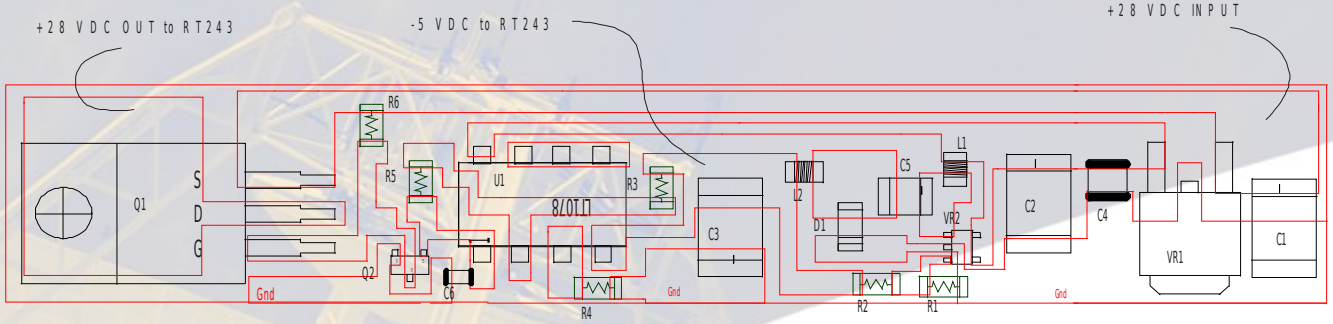
Bias Circuit PCB Design



Assembly Drawing

PCB Negative

Finished Board

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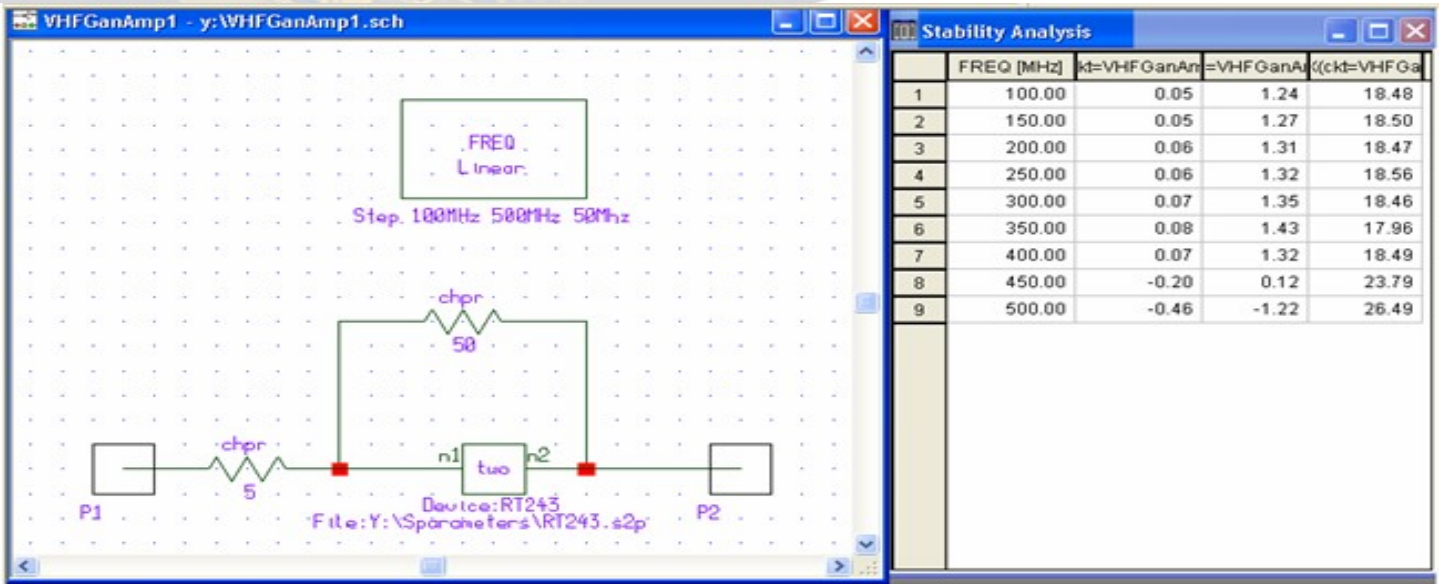
RF Amplifier Design

- Stabilize Device using series input resistor and/or resistive feedback network.
- Check Stability Factor criteria, K>1 and B>0



Stability Analysis

	FREQ [MHz]	kt=VHFGanAm	=VHFGanAu	((ckt=VHFGa
1	100.00	0.05	1.24	18.48
2	150.00	0.05	1.27	18.50
3	200.00	0.06	1.31	18.47
4	250.00	0.06	1.32	18.56
5	300.00	0.07	1.35	18.46
6	350.00	0.08	1.43	17.96
7	400.00	0.07	1.32	18.49
8	450.00	-0.20	0.12	23.79
9	500.00	-0.46	-1.22	26.49

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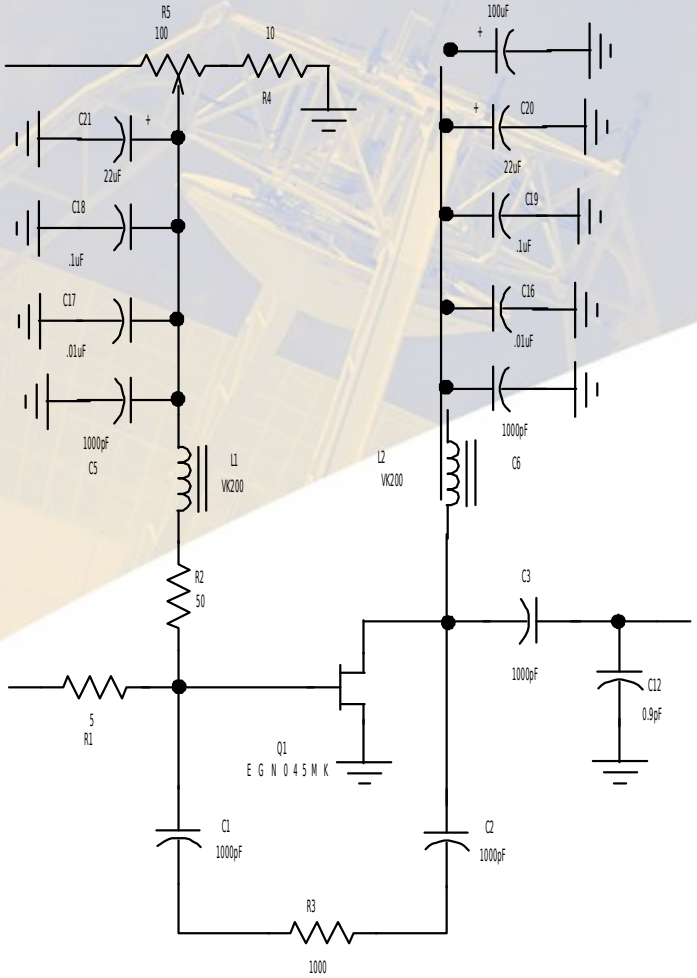
RF Amplifier Design



- Add Gate and Drain feed bias decoupling networks.
- Include 50 ohm resistor on gate for additional low frequency stability and current limiting.
- Add potentiometer on gate so that actual operating point can be adjusted.
- Keep at least 20mA bleed current in potentiometer so that gate current is not starved.

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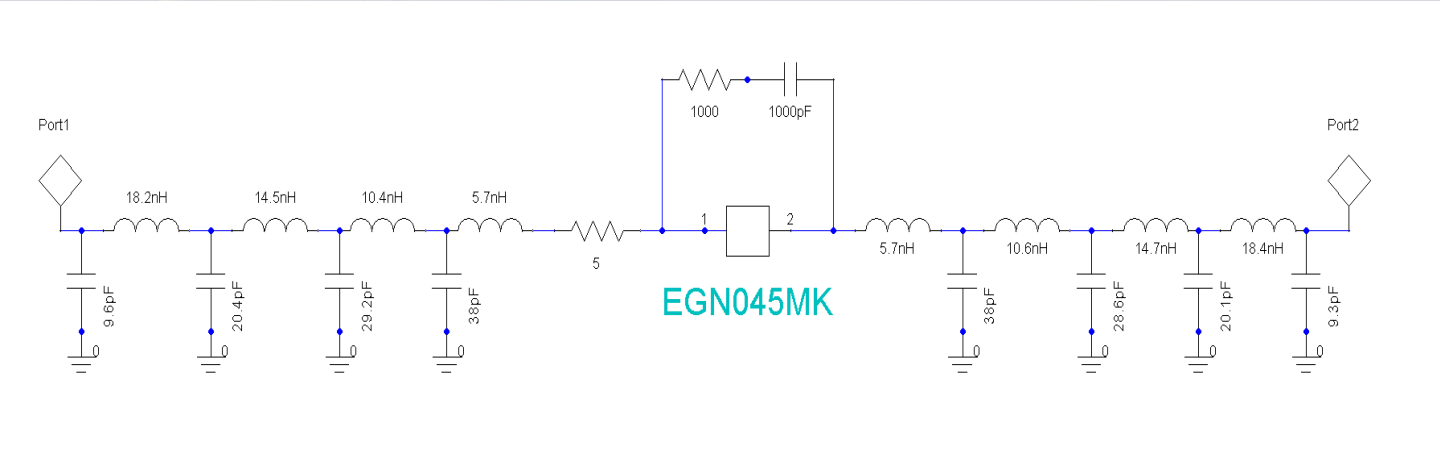
RF Amplifier Design



Linear design schematic in Ansoft SV

- Add (4) section low pass matching network to input and output of device.
- Tune networks for approximately 25dB gain and best possible input and output return loss (at least <5dB)
- Inductors can be converted to “distributed” inductors on PC board.

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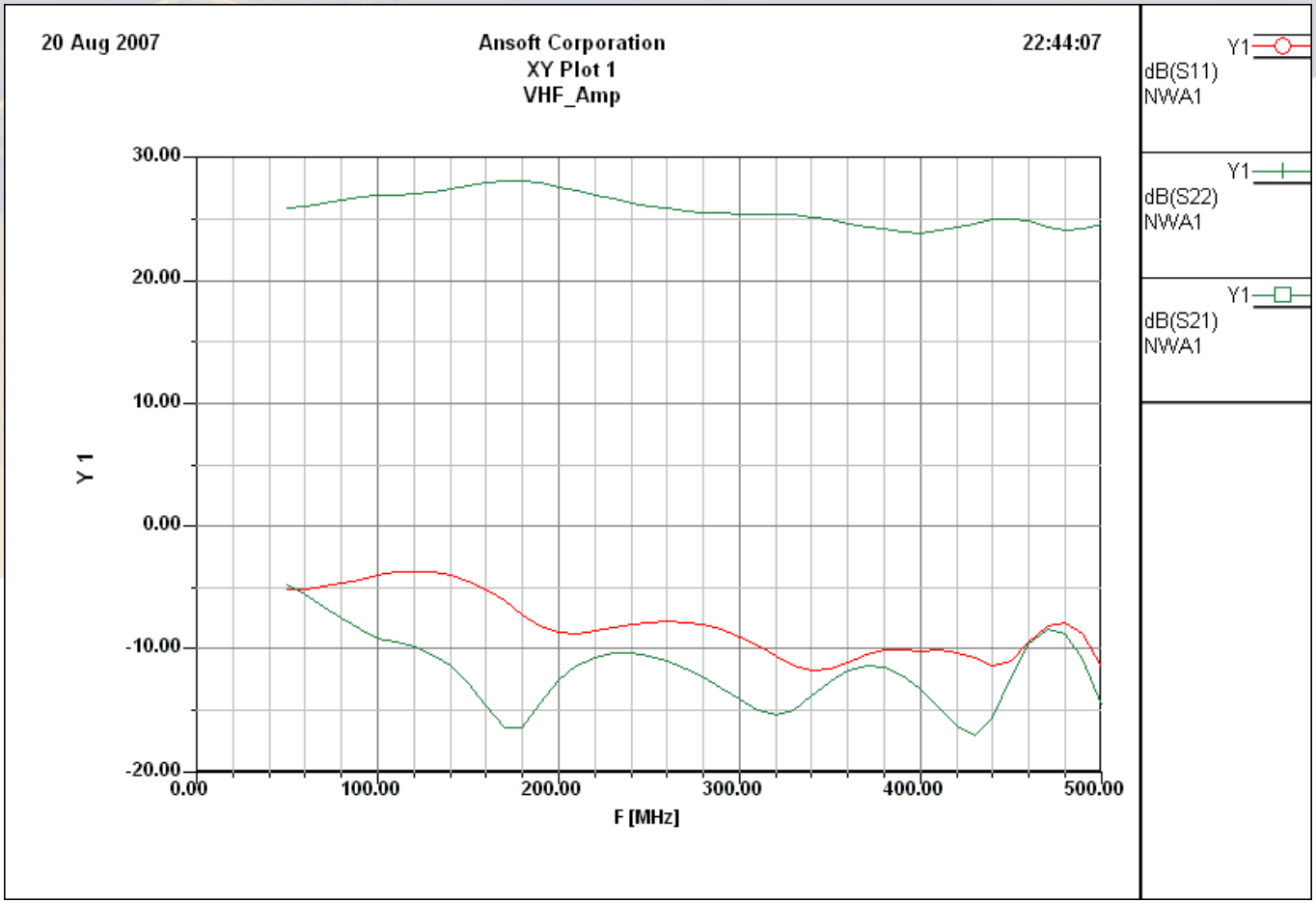
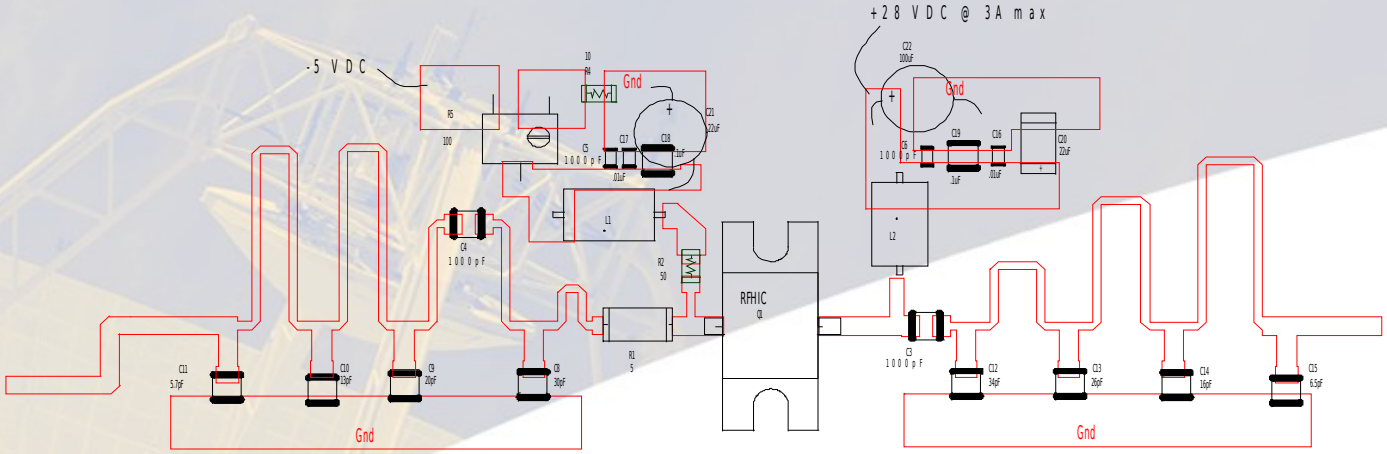
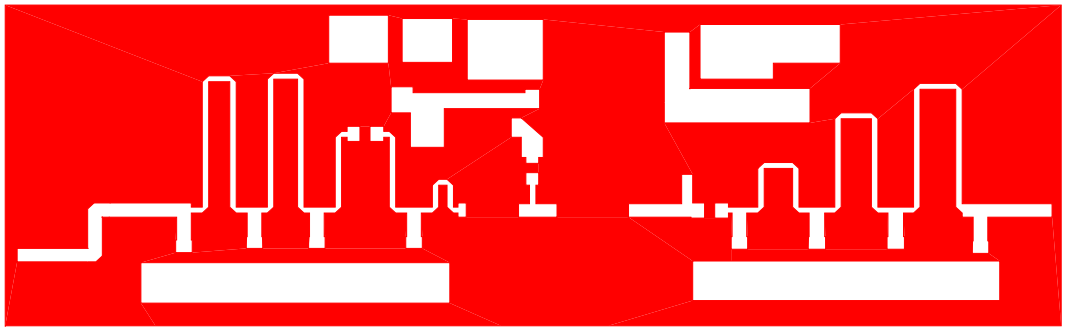
Simulated Gain and Return Loss



RF PCB Design



RF Amplifier Assembly Drawing



PCB Negative

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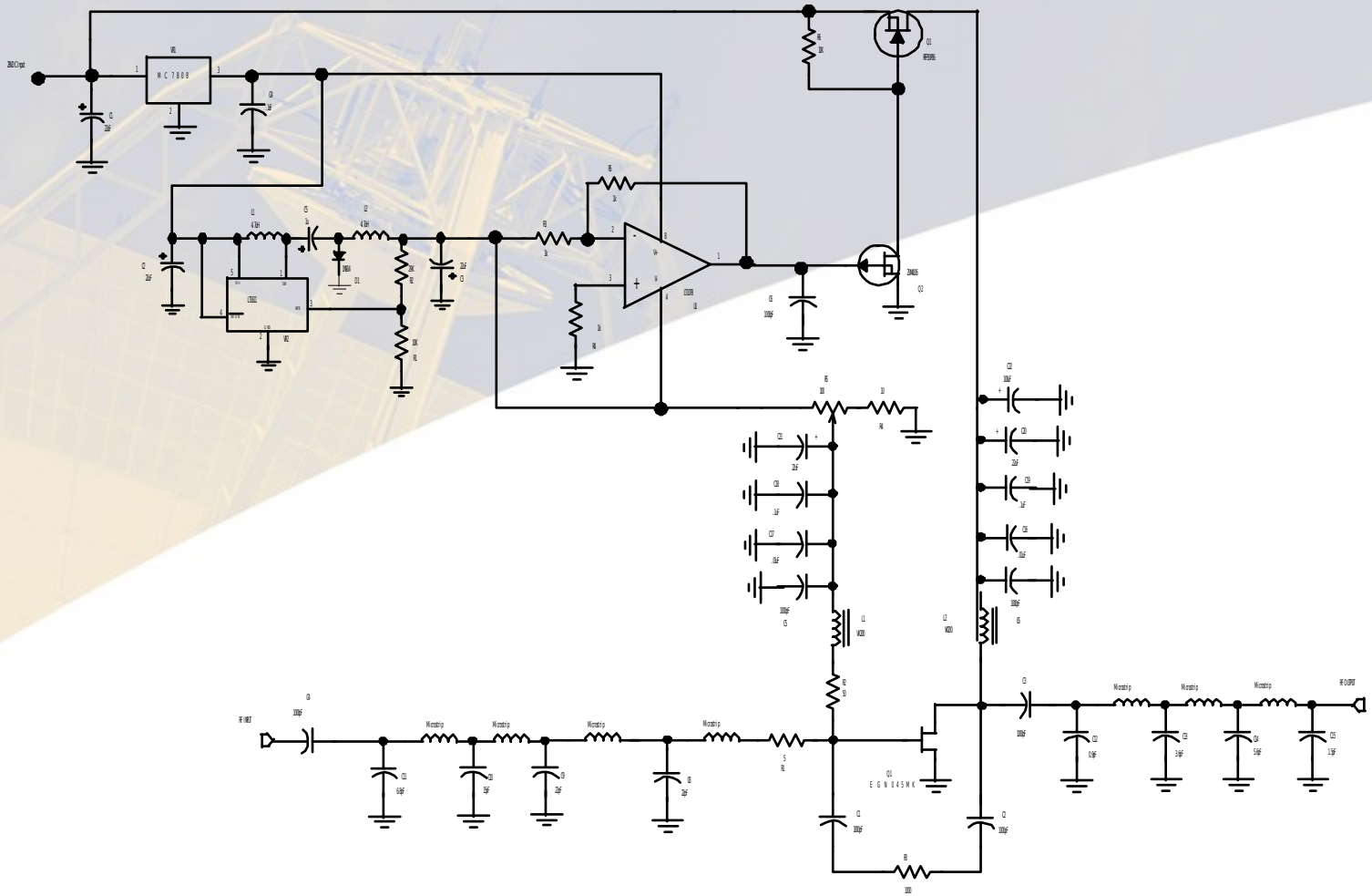
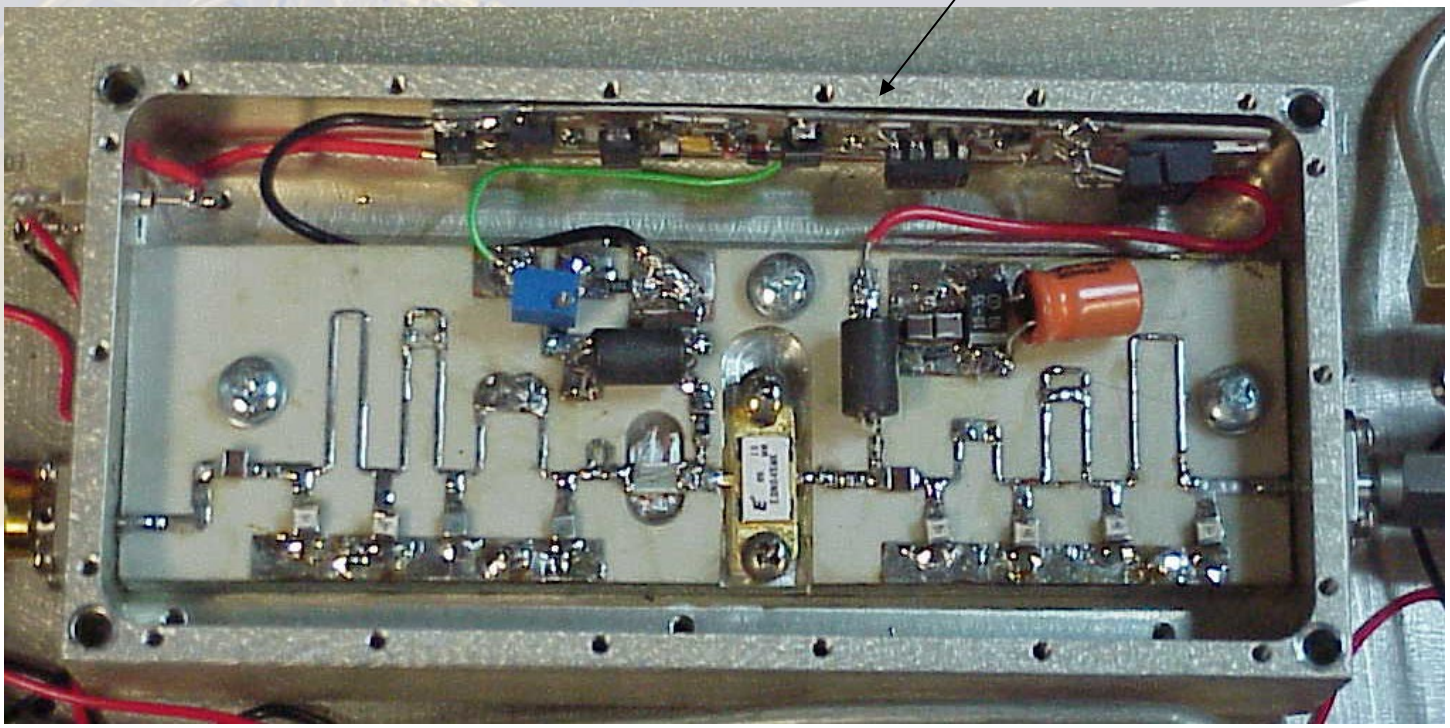
Combined RF & DC Schematics

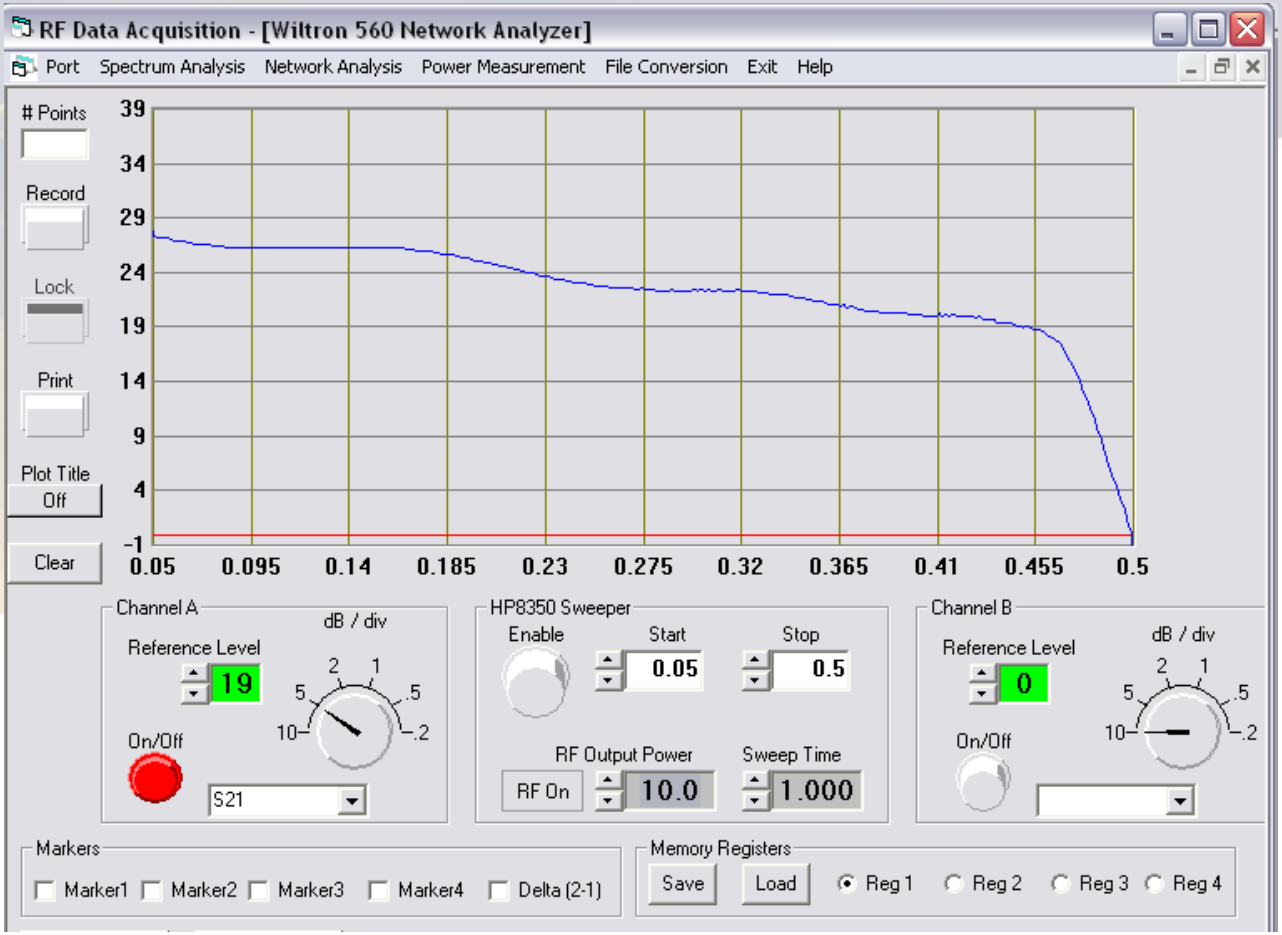

MC7808
LT1021
LT1078
2N7000
MPS06
Microstrip
Microstrip
Microstrip

Assembled Amplifier

Bias Board mounted on side wall



Measured Broadband Gain



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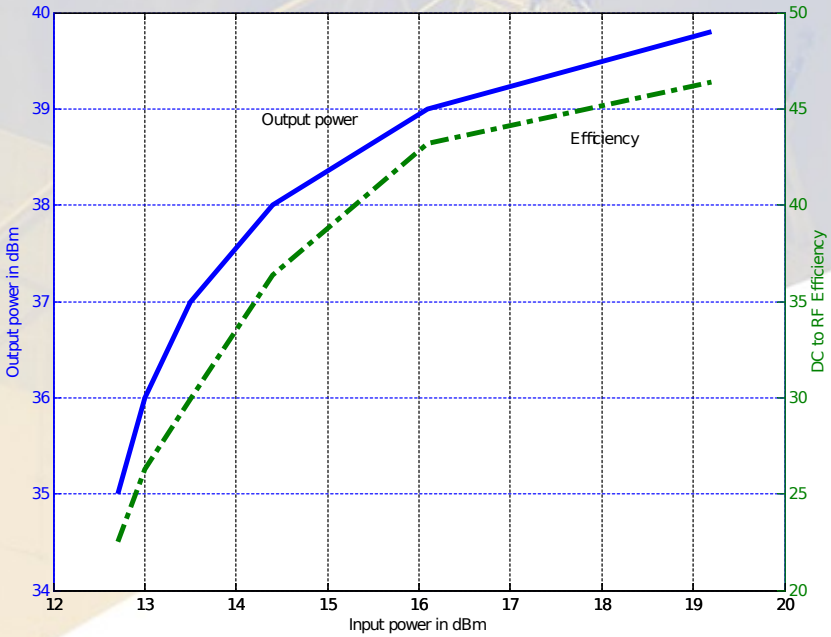
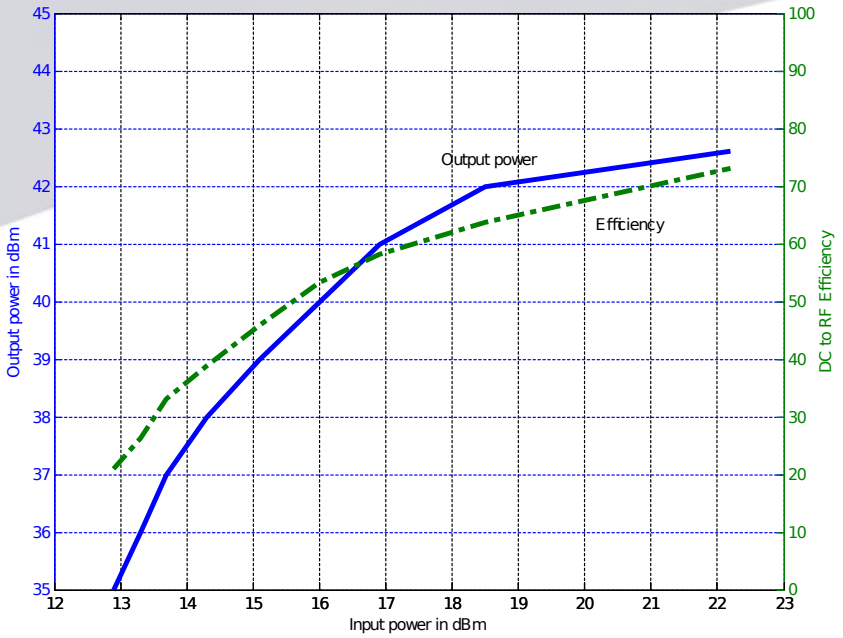
Measured Output Power vs Input Power



Output Power and Efficiency at 50 MHz



Output Power and Efficiency at 146 MHz

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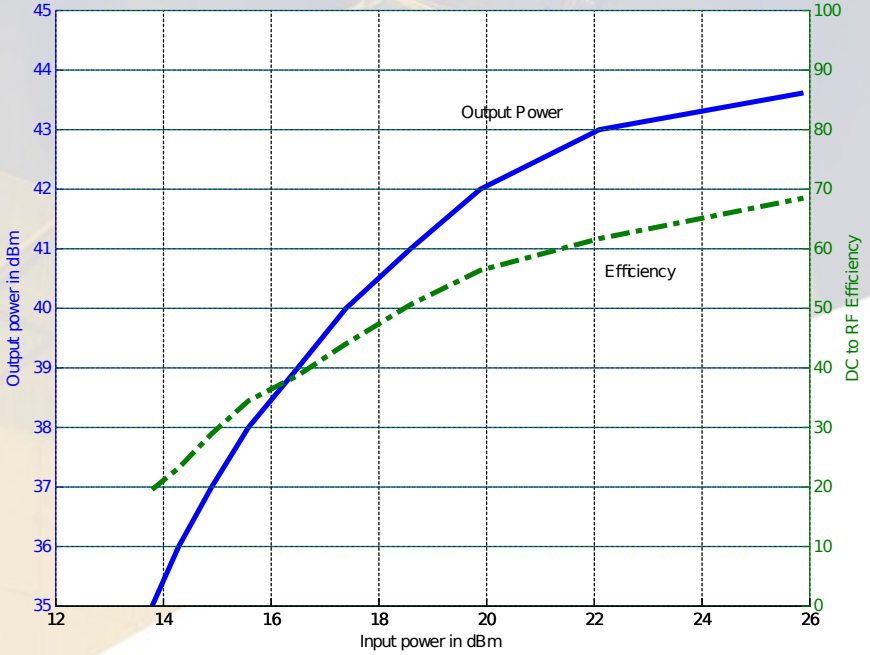
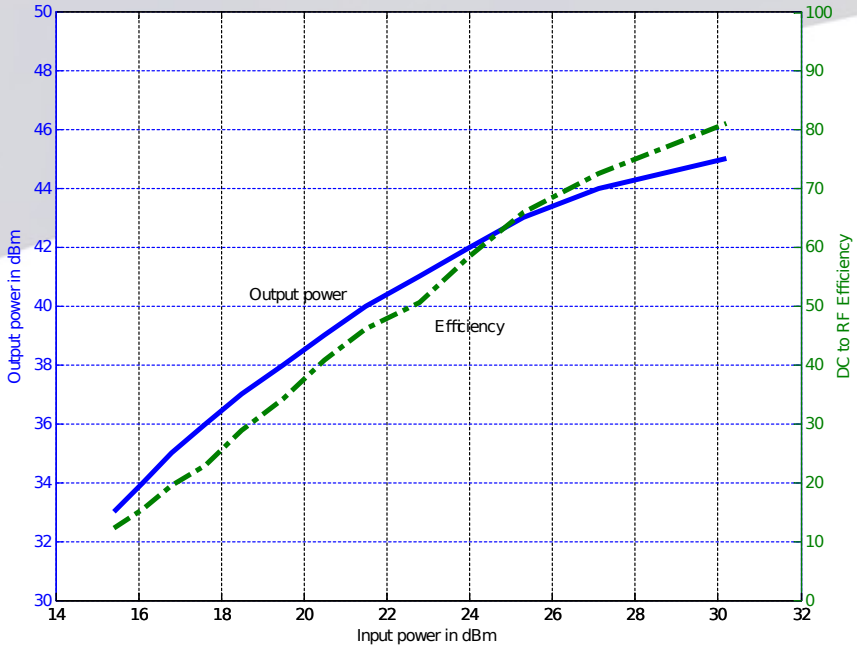
Measured Output Power vs Input Power



Output Power and Efficiency at 220 MHz



Output Power and Efficiency at 440 MHz

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Efficiency Summary

Frequency	Psat, dBm	Psat, Watts	Drain Current @ 27 VDC	DC-RF Efficiency
50 MHz	39.8	9.55	.76	46.4
146 MHz	43.0	20.0	1.00	73.8
222 MHz	43.6	22.91	1.24	68.3
440 MHz	45.0	31.62	1.44	81.2

Very good efficiencies obtained using simple, linear design techniques. Demonstrates the tremendous potential of GaN based Amplifiers.

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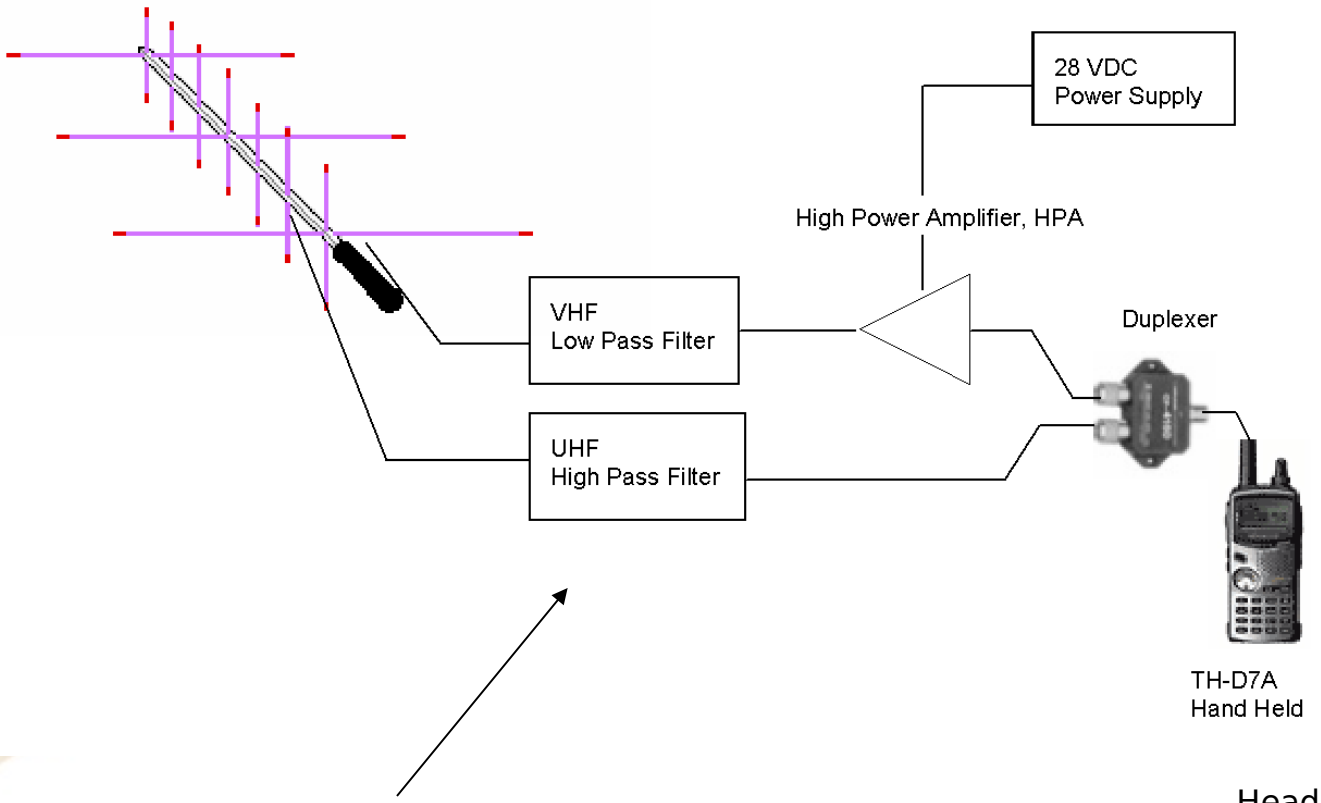
AO51 Operation



Filters optional
Only if full duplex operation is desired

Headset with boom mic recommended
for full duplex to avoid feedback

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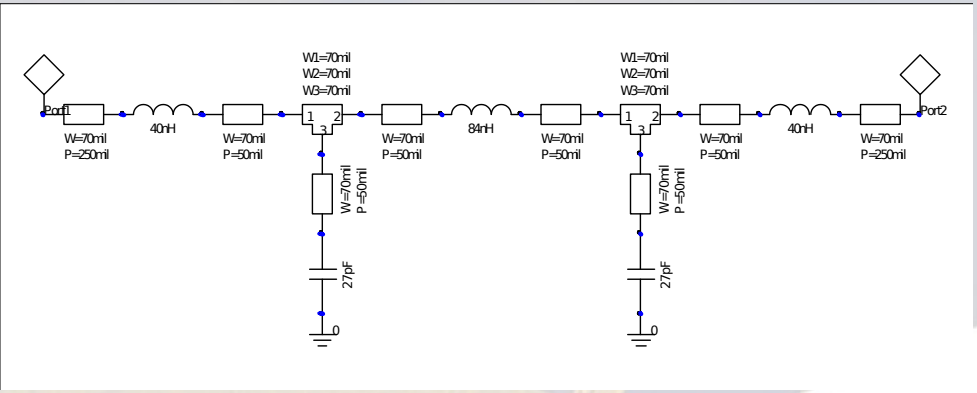
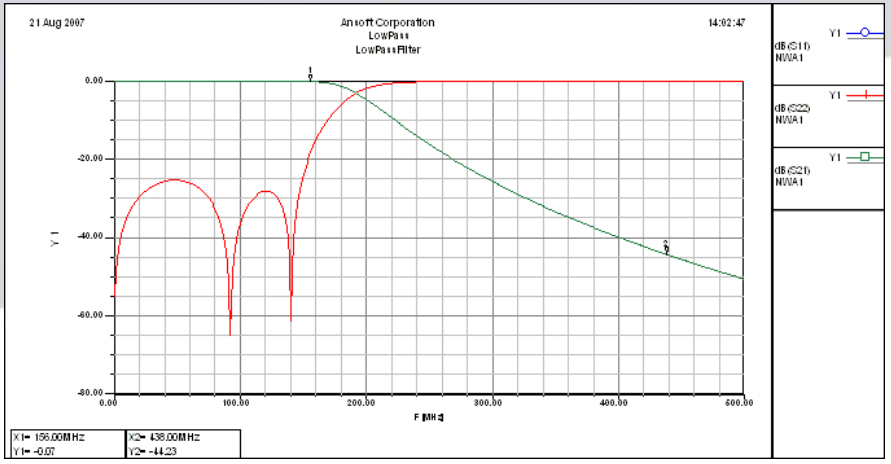
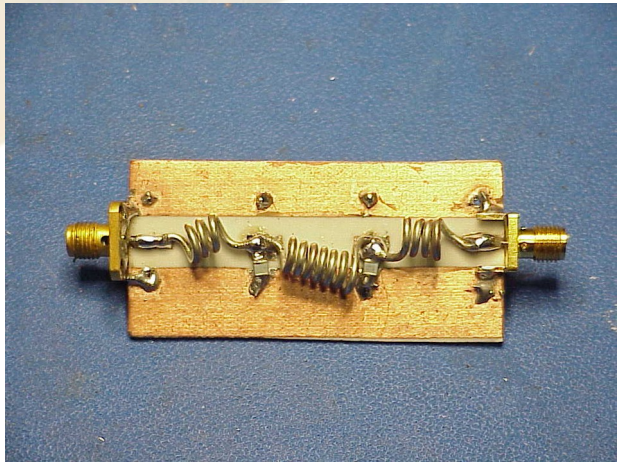
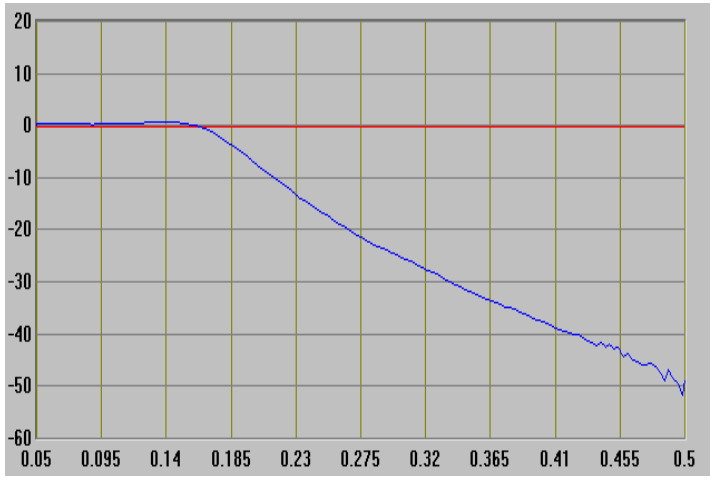
VHF Low Pass Filter Design









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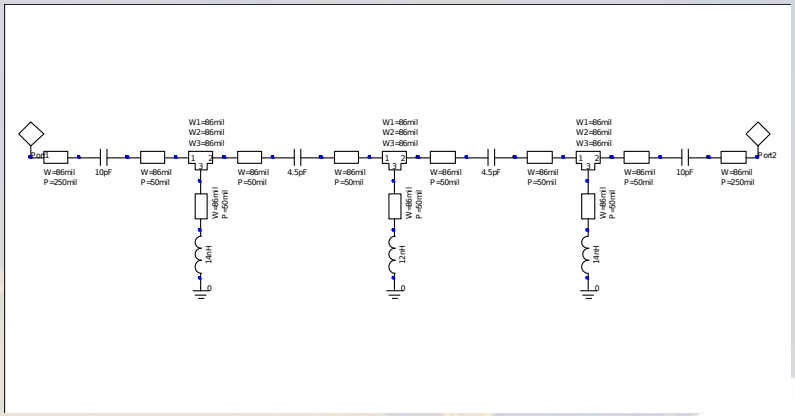
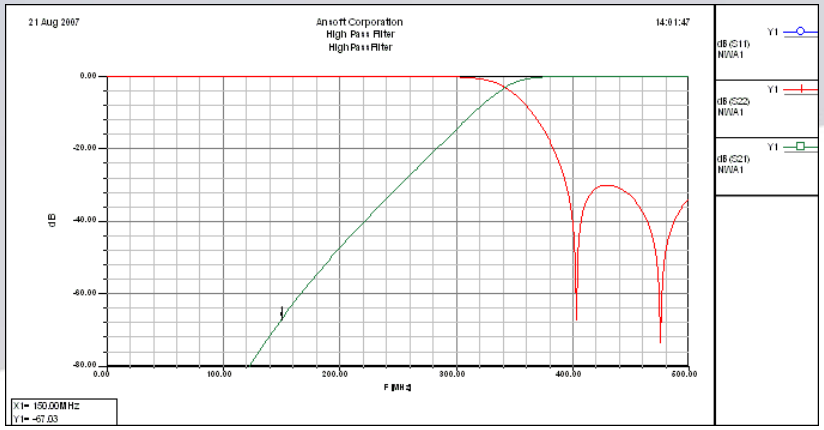
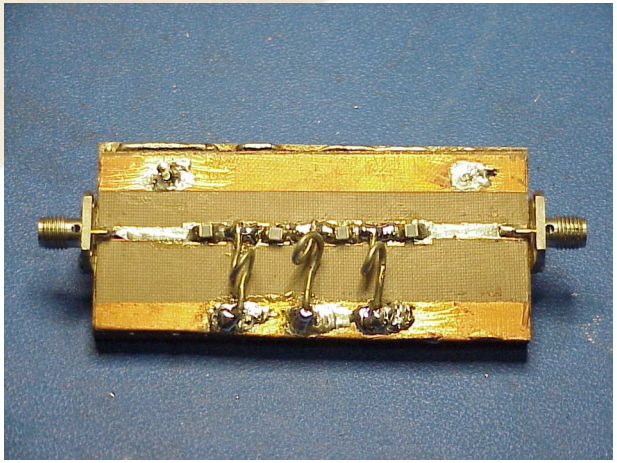
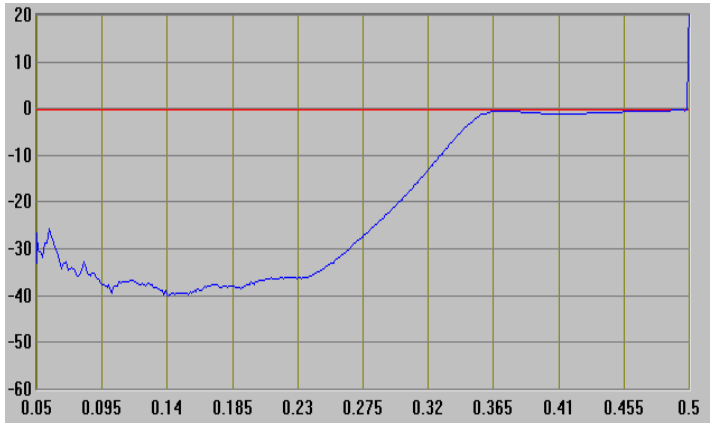
UHF High Pass Filter









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Kenwood TH-D7 Setup for AO-51

- Select Band A and Set Uplink Frequency, 145.920 MHz
  - [VFO] [ENT] 145920
- Set PL Tone of 67 Hz.
  - [F] [2] select 67 then [F] [1] to toggle tone on/off – tone indicator should be displayed
- [DUAL] to enable Dual Band Mode
- Select Band B and Set Downlink Frequency, 435.300 MHz
  - [VFO] [ENT] 435.300
- Change the default step size from 25KHz to 5KHz for fine tune doppler correction.
  - [F] [8] select 5 KHz [OK]

- When listening for the satellite as it comes up on the horizon, make sure to tune receive frequency up toward 435.310 MHz.
- Continue to tune frequency toward 435.290 MHz as satellite moves away to horizon.
- Will need to toggle the [A/B] button to transmit Band A when transmitting
- Keep transmit frequency fixed on 145.920 MHz.

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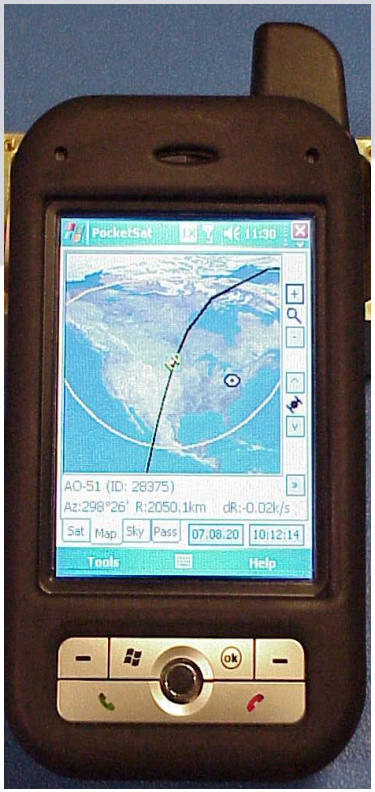
AO-51 Station in Operation

AO51 Station with amplifier



PocketSat+ Satellite Tracking program
running on AudioVox 6700
Cell Phone/PDA

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Summary

- Extremely Broadband and High Efficiency High Power Amplifier has been successfully designed and tested.
- Introduction to GaN Device Technology
- Simple Design techniques along with free software have been used in the design of the HPA.
- Start designing, building, and experimenting!!!!